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Literature Review: Use of Electronic Devices and Impact on Acquisition and Retention of Information

Juliana Goh
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"Literature Review: Use of Electronic Devices and Impact on Acquisition and Retention of Information"

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Executive Summary

This technical report provides a review of literature on the issue of how information is acquired, retained, and understood on electronic displays versus paper. This issue is of particular importance given the increased use of Electronic Flight Bags (EFBs) on aircraft in commercial operations. These EFBs provide a device to store and view documents, charts, and maps that have traditionally been viewed on paper.

This report is divided into five sections. Section 1 provides an introduction. Section 2 reviews literature on how textual and spatial information are acquired on electronic displays versus paper. Section 3 reviews literature related to issues to consider in the use of electronic displays for information acquisition. Section 4 provides a set of conclusions and recommendations. Finally Section 5 provides a reference list of the work reviewed in this report. The reader is encouraged to read Section 4 of this document for a quick summary of the review.

In general, acquiring textual information has been shown to be slower when presented on electronic displays than with paper. This finding was based on studies that used extended reading tasks. However, the pilot and/or crewmember engages in targeted reading over much shorter periods of time. The implications of slower reading performance from electronic displays may therefore not be operationally significant for a pilot or crewmember. Variables related to visual quality of the information (e.g. resolution, contrast ratio, etc.) were found to contribute to these performance differences and may be minimized when certain issues of legibility are addressed.

In addition, electronic displays are useful when depicting spatial information given that layering of information is possible on electronic displays but not on paper. This capability allows users to decide what information is needed and when, while at the same time reducing the cost of information access when different types of information need to be integrated in one location.

To ensure that electronic documents are well designed, issues related to legibility and navigation must be considered. The reader is encouraged to consult the following resources for basic interaction issues:

- Human Factors Considerations in the Design and Evaluation of Electronic Flight Bags (EFBs) Version 2. (Report No. DOT-VNTSC-FAA-03-07). Cambridge, MA: USDOT Volpe Center. (Chandra, Yeh, Riley, Mangold, 2003)
- FAAOrder 8900.1: Flight Standards Information Management System, Electronic Flight Bag Operational Authorization Process (Volume 4, Chapter 15)
- AC 25-11A: Electronic Flight Deck Displays
- AC 120-76B: Guidelines for the Certification, Airworthiness, and Operational Approval of Electronic Flight Bag Computing Devices
- AC 20-173: Installation of Electronic Flight Bag Components

With regards to navigation, the use of links in text must be used prudently. They should not be used when a linear course of action is required of the pilot or crewmember (e.g. in a checklist) and an overview of link selections will reduce the likelihood of the user getting lost. Being able to return quickly to an original location within the text is also beneficial. In addition, studies of how users use paper indicate the utility of personalizing documents. Specifically, providing the ability to highlight, annotate, bookmark, and underline enhances the use of electronic documents, and retaining these edits and annotations in subsequent updates to electronic documents or manuals is recommended.

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1 Introduction

The Electronic Flight Bag is used in commercial and general aviation as a means to provide pilots and/or crewmembers with an electronic equivalent of charts, manuals, checklists and other paper supported functions traditionally provided in paper form. The EFB has the advantage of simplifying the logistics involved in updating these documents and potentially saving weight on the airplane. Indeed, the use of tablets (e.g. Apple's iPad) as EFBs has become popular in recent years given their portability and relatively low cost.

The Federal Aviation Administration (FAA) in Advisory Circular (AC) 120-76B defines EFB as follows:

"*An electronic display system intended primarily for flight deck use that includes the hardware and software necessary to support an intended function. EFB devices can display a variety of aviation data or perform basic calculations (e.g., performance data, fuel calculations, etc.). In the past, some of these functions were traditionally accomplished using paper references or were based on data provided to the flightcrew by an airline's flight dispatch function. The scope of the EFB functionality may include various other hosted databases and applications. Physical EFB displays may use various technologies, formats, and forms of communication. An EFB must be able to host Type A and/or Type B software applications.*"

A tablet or other personal electronic devices (PEDs) that hosts Type A or Type B software applications may also be considered an EFB. With the increased use of electronic devices to display information that has traditionally been displayed on paper on the aircraft, there is a need to understand how this may or may not impact the acquisition and retention of information. Specifically, are there differences in how well information is acquired, understood, or remembered when it is displayed electronically versus when it is displayed on paper? If so, what are the issues to consider and are there methods to improve the usability of such electronic media so that these performance differences may be minimized?

The literature review presented in the following sections will address the above questions through a review of relevant scientific and industry literature. These include articles from academic journals and conference proceedings as well as industry publications. The reviewed literature was identified using a keyword search of databases that included material from academic journals and conference proceedings. Given a fixed project schedule of 3 months, the review presented here is of 43 articles that address the issues related to the use of electronic devices and how they impact the acquisition and retention of information. This review of 43 articles is not an exhaustive coverage of the literature and the reader is encouraged to consult the reference list in this document as well as within the cited articles for further examination of the topic.

The review will first describe findings about differences in acquiring, retaining, and comprehending textual and spatial information when using paper versus electronic media. Second the review will describe findings related to different factors that could affect the legibility of and ease of finding information presented via electronic media. Finally, the findings are summarized and recommendations provided regarding how to optimize the presentation of information via electronic media. It is expected that the review and recommendations presented here will provide the basic knowledge needed by personnel within the Federal Aviation Administration (FAA) who are tasked with writing regulatory guidance regarding the use of EFBs, or assessing the usability of EFB products that are being installed on aircraft.

2 Paper versus Electronic Displays in Information Acquisition

Pilots and/or crewmembers use information from EFBs that is both textual (e.g. operations manuals, quick reference handbook, checklists) and spatial in nature (e.g. approach plates, sectional charts, airport diagrams, arrival and departure procedures). This section provides a critical review of the literature that compares presentation of both types of information electronically versus on paper. Since the literature specific to the aviation domain is limited, literature from other domains is also considered (e.g. education, healthcare, transportation) and the applicability of its findings to aviation is discussed.

2.1 Acquiring Textual Information

Studies have shown that reading speed and reading comprehension from electronic media is sometimes inferior to, but also sometimes equivalent to, that from paper. The review of this work is divided into studies that used cathode ray tube (CRT) displays and those that used non-CRT displays (e.g., Liquid Crystal Display (LCD)). This distinction loosely correlates with studies conducted in the 1980s and those conducted after that. This distinction is important because the quality of the display has an impact on the legibility of the information presented, and this in turn could affect reading performance. The studies that used CRT displays tended to find that reading from electronic displays was slower than reading from paper, leading this set of early research to focus on understanding the variables that could improve the display of information so as to reduce these differences in reading performance. With the availability of better quality displays, however, the more recent studies have focused on variables other than visual quality to explain differences in reading from paper versus electronic displays.

2.1.1 Studies with CRT Displays

In a study conducted by Muter, Latremouille, Treurniet, and Beam (1982), participants were asked to read continuous text from a television screen for an extended period of time (two hours) or from a book. The text used were short stories and the authors kept the text structure (number of rows of text per page, number of characters per row and number of words per page) as similar as possible across the two media. In addition to measuring reading speed and comprehension, the participants also provided subjective reports of discomfort (e.g. fatigue, eye strain, and dizziness). The results of the study showed that participants read at an average rate of 158.9 words/min from the television screen which was 28.5% slower than the average reading rate from paper (222.3 words/min). Comprehension scores, however, showed no difference between reading from the television screen or from the book. Participants also reported experiencing some amount of eye strain, dizziness, and fatigue, but this did not differ across the two reading conditions.

The study by Muter et al. (1982) exemplified the studies conducted in the 1980s. These studies compared reading speed, comprehension, and proof reading accuracy using CRT displays versus paper and the finding that performance was slower with CRT displays was replicated by various other authors (Gould and Grischkowsky, 1984; Gould et al. 1987a; Kruk and Muter, 1984; Wright and Likorish, 1983). The studies conducted subsequent to Muter et al. (1982) attempted to understand and isolate the variables that led to poorer reading performance on the CRT displays. On such study was conducted by Gould et al. (1987b).

Gould et al. (1987b) summarize the findings from a set of experiments they conducted, examining the impact of image quality on reading performance. In four experiments, participants were asked to proof read documents on CRT displays and paper and their speed and accuracy were measured. Between experiments, the authors manipulated addressability, refresh rate, and polarity of the CRT display used. Using a within-subjects design in which participants used all the different CRT displays in the proofreading task, the authors managed to identify factors which could lead to improvements in reading from CRT displays to the point where it was equivalent to paper. The authors concluded that variables such as polarity and resolution contributed to the improvement in task performance on CRT displays. They also note that while the contribution of each of these variables is small, the variables interact and the end effect is cumulative.

Another study that has demonstrated equivalence between paper and electronic displays for reading was conducted by Muter and Maurutto (1991). The authors demonstrate, however, that “skimming” from an electronic display may be worse than that for paper. Muter and Maurutto (1991) compared the use of a “higher quality” CRT display than those used in the reading studies in the 1980s. The authors also incorporated other improvements to the text that had been shown to benefit reading from a CRT display. These improvements included using double spacing and negative contrast (black text on a white background). The authors used short stories as the test material and asked participants to either read or “skim” the text. The instructions for skimming were to read the text at “three to four times faster than normal to grasp a general sense of the content or to retain only the main points.” A comprehension test was used after each story was read to measure how well the participants understood the material. Muter and Maurutto (1991) found that there was no difference in reading speed between reading from a CRT display and from paper with the improved CRT. Indeed, they found that the effective reading rate (reading rate multiplied by proportion correct on the comprehension test) was marginally better with the CRT display than with paper. This difference was, however, not statistically significant. For the skimming task, skimming from the CRT was 41% slower but comprehension was better compared to that for paper. Overall, the effective skimming rate was statistically significantly lower (140.8 word/min) in the CRT condition than for paper (179.6 word/min). The results of this study suggest that improvements in the quality of the display is one factor that could lead to equivalent reading performance when reading from CRT displays and from paper, but this equivalence in performance was not demonstrated for the task of skimming text.

This section reviewed a sample of the early studies that compared reading performance on electronic displays versus paper. These studies used CRT displays and tended to find that reading performance was poorer on CRT displays than on paper. In attempting to isolate the variables that could enhance the usability of these displays for reading, the authors were interested in increasing the legibility of the information that was being presented. Factors such as contrast ratio and resolution were identified to be critical in this respect. The issue of legibility will be discussed further in Section 3. The next section will review more recent studies comparing reading from electronic and paper media using non-CRT displays and highlight the issues that have emerged from this body of work.

2.1.2 Studies with LCD and other non-CRT displays

More recent comparisons of reading performance between electronic and paper media have shown mixed results, despite the improvement in display technology. One such study is described in a technical report by Miratch (n.d.). This study compared reading articles from a tablet (iPad) versus from a newspaper. Reading the same articles on both mediums, readers took the same average amount of time to read an article regardless of whether this was done on the iPad or in print. However, it was noted that the gaze duration was longer with paper (275ms) than with an iPad (231ms). This translated to better retention of information from paper than from the iPad; 90% of participants remembered reading an article when using paper compared to 70% of participants when using the iPad. Indeed, while reading was more efficient with an iPad (35% of articles read on the iPad, compared with 18% on paper), the results suggest that the reading process was also more superficial.

Research specifically on the use of EFBs to perform typical flight deck tasks is limited. One such study conducted by Shamo, Dror, and Degani (1998) examined the need for “information integration” and “multiple search mechanisms” to help pilots find the information they need from an EFB to perform tasks typical of those carried out on the flight deck. Specifically, the authors compared the use of paper versus an “Integrated Crew Information System” (ICIS) which may be considered an EFB in that it is a semi-portable electronic device that contained material such as charts and manuals. Twenty commercial pilots were asked to find information in their documents and perform performance calculations so as to be able to answer questions presented to them. An example of these tasks included searching the Minimum Equipment List (MEL) for information on the Auxiliary Power Unit (APU) Check Valve and finding the takeoff speeds from a contaminated runway at Chicago O’Hare airport. These tasks were performed sitting at a workstation and not in a simulator.

Shamo, Dror and Degani (1998) measured three types of responses as well as the time it took to complete the tasks. The three types of responses were correct, incorrect, and skipped responses. The results showed that pilots had fewer incorrect and skipped responses when using the ICIS compared to paper. These differences were statistically significant. The amount of time it took for the pilots to complete the tasks was also faster with the ICIS than for paper. On average, pilots were 58 seconds faster in completing the tasks with the ICIS than with paper, a difference that was statistically significant. The authors postulated that these performance differences may be explained by the ICIS having integrated sources of information. This integration in turn resulted in pilots being less likely to miss information they needed to complete their tasks. The ability to integrated different sources of information within one location will be further discussed in the next section as an advantage of electronic displays in the acquisition of spatial information.

In the use of electronic displays for reading, Ballantyne (2008) has suggested that consideration must be given to a user's prior experience with electronic media when examining whether there are performance differences acquiring, retaining, and comprehending information from paper versus electronic displays. This is especially true with current trends in consumer electronics. Younger users are exposed from an early age to electronic devices in many aspects of their lives and may be more comfortable using them. Older users, on the other hand, may find greater difficulty transitioning to electronic devices for tasks that have traditionally been done on paper (e.g. reading). Miratech's (n.d.) report did not provide detail on the population that was tested, but insight into the issue of how younger populations respond to reading from paper versus electronic displays was conducted by Kim and Kim (2012).

Kim and Kim (2012) asked senior high school students to complete two comprehension tests. Each passage was presented either on paper or scanned and presented on a Liquid Crystal Display (LCD) monitor. In addition to scores on a multiple choice question test after reading each passage, the students were also asked to provide information regarding their preferred presentation format, their level of comfort with using a computer and having to scroll through text, and how often they use the internet. The results showed that the students read 36% more slowly and scored higher with the text presented on paper than when it was presented on the LCD display, differences that were statistically significant. In addition, almost 85% of the students reported preferring reading from paper. These results were contrary to the notion that the younger generation, being more comfortable and exposed to electronic devices, would read and understand text better from the LCD display than from paper. The authors suggest that the need to scroll through the text on the LCD display was one possible reason for the disadvantage observed. Their explanation is supported by other authors (e.g. Ballantyne 2008; Mangan 2008) who have indicated that the additional interactive features that electronic media provide and/or require (e.g. scrolling) can be a distraction to the reader. This issue is discussed more thoroughly in Section 3.2.

Another study, that involved reading patient records in a hospital setting, found no differences in the reading performance (speed, accuracy, and comprehension) between reading from paper or from a computer screen. Holzinger et al. (2011) conducted a study in a real world hospital setting, requiring 111 medical professionals to read gynecological and internal medicine reports. They read each report either on paper or on a computer screen. Reading speed and accuracy were measured and comprehension was measured by a Chunked Reading Test. In addition to finding no differences in the objective measures between reading on paper and reading from a computer screen, the authors found that 100 out of the 111 clinicians indicated a preference for paper. The reasons provided included its "flexibility," "mobility," and "ease of use" compared to a notebook screen. The users also liked having the ability to write notes.The research from non-aviation specific domains has shown that reading from electronic media is at best equivalent to reading from paper. The early research conducted in the 1980s used displays that were primitive by today's standards and tended to show that reading from electronic displays was inferior to reading from paper. Even with better quality displays and a better understanding for how to improve the legibility of text presentation on electronic displays, more recent research has still shown mixed results. It is important to note, however, that these non-aviation specific results must be interpreted within the context that they were collected and these contexts may not necessarily be similar to that experienced by crewmembers on the aircraft on several fronts.

First, the studies that have been reviewed have used tasks that may not be similar to what is typically conducted on the aircraft. While crewmembers do read textual information, they do not use their EFBs for extended reading tasks such as those used in the studies by Muter et al. (1982), Muter and Maurutto (1991) or Miratech (n.d.). Crewmembers use their manuals, checklists, and quick reference handbooks as reference material during which the reading is very targeted and likely to occur over a very short period of time. For example, a crewmember may wish to consult the operations manual to determine the meaning of certain indications on the Navigation Display. With such short periods of reading, any differences found in reading rates between reading from paper and reading from electronic displays may not have operationally significant performance implications. Indeed the aviation specific study by Shamo, Dror, and Degani (1998) showed a benefit to using an electronic display over paper because of the benefits of information integration. Secondly, the reading material used in these studies tends to be fiction or material to which the reader may not be familiar. This is another difference that limits the applicability of the results to the use of EFBs on the aircraft. Crewmembers already have domain knowledge of the material they refer to in their manuals and this could aid the comprehension of the material that they read.

In addition to acquiring textual information from their manuals and other handbooks, pilots also refer to charts and maps in the course of a flight. These include airport diagrams, approach plates, sectional charts, and charts showing arrival and departure procedures. The next section will review the literature on acquiring spatial information from electronic displays compared to paper.

2.2 Acquiring Spatial Information

Much of the research comparing the acquisition of spatial information via electronic displays or paper has focused on comparing the use of electronic charts versus paper maps in aviation and surface transportation. In general, electronic charts have been shown to be superior to paper maps. It must be noted, however, that the advantage an electronic chart display has over a paper map is not in the medium of presentation per se, but that an electronic display allows the selective layering of information. This provides the user the ability to integrate different sources of information onto one location (e.g. overlaying route of travel or ownship symbol on the map), thereby reducing the attentional workload of the user (Kroft and Wickens, 2002) and allowing the user to decide what information is needed and when. In contrast, a paper map shows all information all the time. This can clutter the map, making the search for specific information potentially difficult.

In the field of surface transportation, Lee and Cheng (2008) compared the use of a portable navigation system and paper map on driving performance, involving real life driving in an urban and rural setting. Thirty two students were divided into two groups. The participants in the first group used the portable navigation system and were instructed to follow the route guidance feature. The participants in the second group were provided a detailed paper map and allowed as much time as they wanted to plan their route, but were not allowed to write or annotate on the map. All participants were instructed to get to their destination as quickly as possible, but within the speed regulations along the route. The authors developed metrics to measure driving efficiency and driving performance. The results showed better driving efficiency using the portable navigation system than with paper. Drivers took less time and covered less distance to reach the destination using the navigation system compared with paper. Driving performance was also better when the navigation system was used. Average speed was higher, average yaw rate and the standard deviation in yaw rate were lower for drivers who used the navigation system, suggesting better control of the vehicle. All these differences were statistically significant. The benefit of having an electronic display that shows both the route of travel and the map has been replicated by others (e.g. Srinivasan and Jovanis, 1997). While researchers have cautioned that the use of such systems places additional demands on a driver's attention (Dingus, Antin, Hulsen, and Wierwill, 1989; Antin, Dingus, Hulse, Wierwille, 1990), there is also evidence that experience with such systems can lead to safer use (Dingus, Hulse, Mollenhauer, Fleischman, Mcgehee and Manakkal, 1997).

Similar comparisons made in the field of aviation have also demonstrated the benefit of having an electronic moving map display (e.g. Batson, Harris, and Hunt, 1994, Battiste, Downs, and McCann, 1996; McCann, Foyle, Andre, and Battiste, 1996). Being able to display an ownship symbol on a map of the airport surface provides pilots awareness of their location in relation to taxiways, runways, and other airport buildings. Batson, Harris and Hunt (1994) demonstrated that pilots who used an electronic map with ownship symbol and a taxi route display taxied up to 24 percent faster than pilots who used a paper map under both good and bad visibility conditions, a finding that was statistically significant. The authors suggest that using a paper map required pilots to constantly re-orient the paper map to the direction of travel which in turn affected the speed at which they traveled. In addition, pilots made one third the number of navigation errors with the electronic map than with the paper map. As with the research in surface transportation, increased attentional demands (defined by heads down time) have been cited as a potential issue of using such electronic map displays in the flight deck. Battiste, Downs and McCann (1996) found, however, that compared with paper, even though overall heads down time was higher with electronic maps, the amount of time spent heads down each time the pilot looked down, was less than that for paper. Crew workload was also lower with the electronic map display than with paper.

With an understanding of the literature on how electronic displays compare to paper in the acquisition of textual and spatial information, the next section will review literature that discuss the issues that need to be considered in maximizing the benefits of using electronic displays. The review will also cover literature that compares different techniques that could optimize the use of electronic displays.

3 Considerations in the Use of Electronic Media for Information Acquisition

The use of electronic displays to acquire information requires consideration of several factors: legibility, navigation, and customization. Legibility refers to the clarity with which information is presented to the user. Navigation refers to the ease with which the user is able to locate him/herself within the body of text and go to locations within the text to retrieve the needed information. Finally, customization refers to the ability to interact with the electronic display or document in a manner that supports an individual's cognitive activities. The following reviews the literature that describes these issues.

3.1 Legibility

Information presented on electronic displays must be legible for it to be acquired accurately. The issue of legibility was of greater concern when electronic displays were not as advanced as they are today. Studies which examined reading performance differences between CRT displays and paper also examined variables that would lead to minimizing the performance decrement that was sometimes observed with CRT displays. For example, Muter et al. (1982) examined how proportional and non-proportional horizontal spacing affected reading speed and comprehension. Gould et al. (1987b) investigated variables such as character size, font, polarity, contrast, and aspect ratio.

The issue of legibility is less of a concern to researchers and designers in the present day given the development of design standards and improvements in display technology. The reader is referred to Muter (1996) who provides a comprehensive discussion of variables to consider in designing electronic text, including words per screen, resolution, and interline spacing. For design guidance, standards such as the FAA Human Factors Design Guide for Acquisition of Commercial-off-the-shelf Subsystems, Non-Developmental Items, and Developmental Systems – Final Report and Guide (FAA, 1996) should be consulted. While this guide has been used mainly in the Air Traffic Control domain, principles may apply to flight deck displays. In addition, Advisory Circular AC25-11A (Electronic Flight Deck Displays) provides guidance on flight deck displays in general while Chandra, Yeh, Riley, and Mangold (2003) provide guidance on the legibility of text in EFB applications specifically. With regards to legibility, the authors focus on character issues, typeface size, and width and spacing. Other human factors considerations specific to the design of EFBs are also provided.

3.2 Navigation

The term "navigation" is used to describe how users interact and move around electronic documents to obtain the information they need. The use of electronic displays to present information traditionally done through paper has advantages and disadvantages for navigation and these stem from the unique interactions and capabilities available to electronic documents, but not paper. This section will discuss the issues related to these unique interactions and capabilities.

3.2.1 Hypertext

The term "hypertext" describes text that contains links that provide readers the ability to move easily to and from different parts of a document. For example, crewmembers can easily access specific checklists from a top level index or contents page by selecting the appropriate links. This precludes the need to "flip" through irrelevant pages to get to the relevant ones which is an interaction that is characteristic of using paper documents. Since hypertext allows a more flexible and interactive method of reading, some authors (e.g. Spiro and Jehng, 1990) have asserted that this “non-linear” method of reading enables readers to develop deeper and more connected knowledge of a subject matter. For example, pilots who consult their operations manuals may read about how the Primary Flight Display (PFD) displays V speed indications, but could also easily move to the section on how these speeds are calculated if a link is designed into the document.

Hypertext, however, has the disadvantage of potentially causing the reader to “lose his/her place” within a page or the entire document (Dillon, 1992, Frenckner 1993; Hansen and Haas, 1998). As a reader moves from one section of text to another, across pages, sections or chapters, there is the likelihood that the reader will not be able to maintain an overall awareness of where he/she is. Related to this issue, researchers have discussed the additional cognitive load involved in using hypertext. DeStefano and LeFevre (2007) developed a model of how individuals process hypertext and examined the validity of their model by reviewing research that compared different types of hypertext. The authors assert that reading hypertext requires additional cognitive resources that may not be needed in reading from paper which tends to be linear in nature. When an individual encounters a new link within a section of text that he/she is reading, the individual must decide whether to go to this new section of text or remain in the current section. Moving to a new section of text could also lead to further movement into other sections of text. This constant movement into new sections of text is potentially distracting and may interfere with comprehension. Linking closely related information can lead to a development of a rich understanding of the information, but poor linkages serve to impede this process and disorientation may result (Miall and Dobson, 2001; Nielsen, 1990). Reading from paper provides fewer distractions in this respect. Reading from paper is essentially sequential in nature and the reader is not as easily afforded the opportunity to move to an entirely different location of the document compared to electronic documents with links.

McDonald and Stevenson (1996) compared the speed and accuracy of navigating through a document using three types of text: linear, hierarchical hypertext, and nonlinear hypertext. Each of these types of text had an increasing number of links respectively. Hierarchical hypertext only allows movement within a fixed hierarchy; readers can only go between an upper level node and the node immediately beneath it and vice versa. A nonlinear hypertext allows connections and movement between these connections to be made without any fixed structure. The results showed that participants managed to find the information they needed fastest in the linear text condition, next fastest with the hierarchical text structure and slowest in the nonlinear hypertext structure. In the linear text condition, participants only had the option of selecting “Next” or “Back” and therefore moved through the document until the relevant information was found. On the other hand, thehypertext conditions had more options available for navigation. Similar results were obtained by Lee and Tedder (2003) who compared reading time and the retention of information with traditional text, structured hypertext (text arranged in a hierarchy of topics), and networked hypertext. Together, these studies support the notion that the likelihood of disorientation increases with an increased number of links, especially when the links are not structured in a fixed hierarchy. Some researchers have suggested that limiting the number of links and therefore choices for movement into different parts of a document can reduce the likelihood to become disoriented in a learning environment (Shin, Schallert and Savenye, 1994).

The disorientation that may result from the use of hypertext may, however, be mitigated by having prior knowledge of the subject matter. Individuals who have knowledge of a subject matter already have a network of information that helps them piece together information that they may be retrieving in fragments. For example, a crewmember who “jumps” from one section of his/her operations manual to another through links, may not be as disoriented as a reader who has no knowledge of aircraft avionics and systems and how they are related. This assertion is supported by a study conducted by Potelle and Rouet (2003). The authors asked students with different levels of prior knowledge to read text on social psychology concepts in one of three formats: a hierarchical text, network text, and alphabetical list. Comprehension of the information was tested and the results showed that students with poorer prior knowledge benefited from having a hierarchical structure to aid their understanding of the material, but students who had better prior knowledge did not benefit nor were they impeded by the different text structures.

In addition to structuring hypertext in a suitable manner, other interface features have been shown to be beneficial in reducing the likelihood of disorientation. These features have the goal of helping the reader locate themselves within the document, specifically what they have read and where else within the document they can go. Graphical overviews serve this purpose. These graphical overviews contain titles and subtitle, both linked by lines, providing the reader a means to move around the document by selecting these titles or subtitles. In addition to aiding navigation, de Jong and van der Hulst (2002) found that graphical overviews were in general beneficial to learning from hypertext. Hofman and van Oostendorp (1999) have suggested, however, that prior knowledge levels can mediate this effect; low knowledge users may be distracted by attending to the larger structure of the text rather than the more detailed information. This issue, however, is not necessarily applicable to pilots who use electronic documents on their EFBs since we can assume a high level of domain knowledge.

3.2.2 Scrolling

Aside from the use of links, electronic displays also provide scrolling as a method of navigation and interaction. Scrolls are necessary when the amount of information on a page exceeds the display size. Some authors (e.g. Mangen, 2008) have suggested that scrolling on an electronic display serves as a potential distraction to the reader since it “invites” interaction from the user. The issue of scrolling and its impact on the user becomes more of an issue when small displays are used. With smaller displays, users are more likely to zoom and/or scroll to acquire the information they need. Hamblin (2004) conducted two experiments that shed light on this issue.

Hamblin (2004) examined the use of electronic approach plates on an EFB versus on paper and how additional interactions can affect the time it took to find information. In the first of two experiments, 10 instrument rated pilots were provided paper copies of instrument approach plates and trained to use the JeppView FlightDeck (JPFD) software loaded on the CT-100 EFB manufactured by Northstar Avionics. The pilots interacted with the EFB by using the 30 line select keys around the perimeter of the display. The pilots were asked to find information on the approach plates to answer 60 questions. 30 were answered using the EFB software/hardware and 30 were answered using the paper charts. Participants sat at a desk to complete the task. The chart could not be displayed in its entirety on one page on the EFB, so the authors asked questions so that one third each required paging, scrolling and no additional manipulations. The results showed that in general, it took pilots longer to find information with the EFB (mean = 22.20 seconds) than they did with paper (mean = 14.50 seconds). More specifically, the results suggested that it was the additional interactions required on the EFB that led to the slower information retrieval times. Searches that required paging took an average of 11.35 seconds longer than paper and those that required scrolling took an average of 7.37 seconds longer than paper. These differences were statistically significant.

In a second experiment, Hamblin (2004) investigated the use of the EFB compared to paper in a more dynamic environment. Ten instrument rated pilots were required to fly instrument approaches on a PC based aviation training device (PCATD), while communicating with air traffic control and navigating the aircraft. The pilots also had to respond to questions regarding the approach by using the approach plates either on paper or on the EFB. Workload levels were also manipulated by changing weather conditions (cloud ceiling height, crosswind velocity) and the number of communications with air traffic control. The results showed that at low levels of workload, there was no difference in the time it took to retrieve information between paper and the EFB. But at higher levels of workload, the time to retrieve information increased significantly with the EFB, especially when scrolling or paging was necessary.

3.2.3 Zooming/Panning

Zooming and panning are also interactions unique to the use of electronic displays. Zooming allows users to retrieve more detailed information, while panning allows users to move across a particular page at a specific level of detail. These features are beneficial to users in allowing them to decide the level of detail with which they want to view information, but these features have their disadvantages as well. Zooming into a specific part of a map, for example, could result in users losing "the bigger picture" especially when there are attempts to pan across the map at a very detailed level. This issue is especially true for electronic map displays. When viewing an airport diagram, for example, zooming in to a complex taxiway intersection to get a more detailed look also means one may not know where that particular intersection is in relation to the rest of the airport.

A study by Perdersen, Farrell, and McPhee (2007) illustrates the issues described above. The study examined how well students learned to identify geographical features (glacial and karst landforms) using paper maps compared to using electronic maps. The authors were also interested in whether the student's preferences differed between the two methods of presentation and whether performance and preference correlated with the students' learning styles. The study was conducted on 168 students from a geography laboratory class. The results showed that the students' ability to identify the geographic features and their ability to read the maps did not differ between the two mediums. Neither was there an effect of learning style. However, a majority of the students indicated preferring the paper map over the electronic map, the main reason being that they could see "the big picture" on paper. The electronic map, however, required the students to move around if they were zoomed in. Indeed, students indicated that moving around the screen while zoomed in could be frustrating if the computer was slow to respond. For the students who indicated they preferred the electronic map over the paper map, the main reason they provided was that they could more easily “zoom in and out” to get the information they needed, including latitude and longitude information.

Various researchers (e.g. Bartram, Ho, Dill, and Henigman, 1995; Baudisch, Good, Bellotti, and Schraedley, 2002) have investigated user interface techniques that can provide users both a detailed view and the larger “big picture” view of information displayed electronically. The authors compared the use of three different techniques: zooming and panning, overview and detail, and focus and context on various tasks. The overview and detail technique involves multiple windows, one of which shows detailed information while the other shows the information in its entirety. The focus and context technique involves displaying all the information (e.g. an entire map) in lower resolution and more detailed information is brought into focus at higher resolution, all on the same window. One of the tasks used to compare these different techniques was a map task. Participants were shown a 14 x 10 kilometer map of London and were asked to determine which one of two hotels (marked by different colored Xs) was closer to the conference hotel. Participants were asked to balance accuracy and response time. The results showed that participants responded fastest when using the focus and context technique. Using zooming and panning resulted in 39% slower response times while using the overview and detail technique resulted in 27% slower response times. An Analysis of Variance (ANOVA) showed a statistically significant main effect of display type on response time. There was, however, no difference in accuracy across all three techniques.

3.3 Customization

Customization refers to the ability to interact with the electronic document in a manner that supports an individual’s cognitive needs. Understanding how users use and customize with paper will provide insight into the type of capabilities that should also be provided with electronic documents. Studies (e.g. O’Hara and Sellen, 1997; Sellen and Harper, 1997; Schilit, Golvchinsky, and Price, 1998; Nomura, Hutchins, and Holder, 2006) that have investigated this issue have relied mainly on qualitative observations to arrive at their conclusions.

Nomura, Hutchins, and Holder (2006) conducted field research studies at various airlines in Japan and New Zealand, during which they observed pilots in full motion flight simulators and on revenue flights. Sessions in full motion simulators were also videotaped and interviews were conducted with pilots about how they carried out their work. Pilots were observed to make annotations, highlight information, and use “sticky notes” on their charts and flight manuals. In particular, pilots tended to highlight items of critical interest to the safety of flight: runways, landmarks, and obstacles. On approach plates, radio frequencies, the final approach course, altitude constraints at waypoints on the glidepath, and decision altitudes were highlighted. Highlighting was used to help pilots draw their own attention to critical elements of information needed to perform their tasks safely and efficiently. In addition, the pilots reported that the annotations and highlights were used to “maintain familiarity” with the information on their charts, even when these routes, charts and procedures were ones that they routinely flew. The authors also noted that while these practices were common amongst all pilots, that the ability to annotate and highlight information was particularly important to non-native English speakers. These annotations were made in both English and the pilots' native language.

Nomura, Hutchins, and Holder's (2006) findings reflect those found in other industries. For example, O'Hara and Sellen (1997) examined how individuals use paper versus electronic documents online to perform the task of reading, understanding, and providing a summary of a body of text. Even though the task required of the participants in this study differs from that of a crewmember, the authors found that participants also used similar methods to help them attend to and extract specific parts of the text by using annotations. The specific markings differed across participants, but included the use of underlining, asterisks, and notes in the margins. It was also observed that thickness of lines in underlining was used to emphasize and highlight the importance of specific portions of text.

While the above studies provide evidence that customization can enhance the usability of an electronic document, decisions on whether to customize and how to allow customization should be based on a thorough understanding of the user's needs. Usability studies should be conducted to understand the customization tools needed. The provision of customization tools without this understanding may lead to user confusion and distraction.

4 Conclusions/Recommendations

This document reviewed literature regarding differences between electronic displays and paper in acquiring, retaining, and comprehending textual and spatial information. The following summarizes the main conclusions of this literature:

1. Reading from electronic displays has been demonstrated to sometimes be worse and sometimes equivalent to reading from paper.
2. The use of higher quality displays and other text design features (e.g. font, character size, interline spacing) can reduce the performance differences between reading on electronic displays and reading on paper.
3. The results of many of these studies used a test method that involved participants reading continuous text for a relatively extended period of time. We hypothesize that the performance decrements observed in these studies may not necessarily apply to the type of reading that pilots and crewmembers conduct on the aircraft. The latter is more targeted and occurs over shorter periods of time.
4. Electronic displays are beneficial to the acquisition of spatial information given the ability to use layering and decluttering capabilities. This allows the user to decide and choose what information to display and when.
5. There are unique interactions and capabilities that are available to the use of electronic displays but not paper. The use of hypertext, scrolling, zooming and panning, are useful but have their costs. These costs may be mitigated through using other user interaction techniques.

Based on the above conclusions, the following are recommendations for assessing the usability of electronic documents on EFBs:

1. For basic usability issues, the following guidelines should be consulted:
    - Human Factors Considerations in the Design and Evaluation of Electronic Flight Bags (EFBs) Version 2. (Report No. DOT-VNTSC-FAA-03-07). Cambridge, MA: USDOT Volpe Center. (Chandra, Yeh, Riley, and Mangold, 2003)
    - FAA Order 8900.1, Volume 4, Chapter 15, Section 1, Electronic Flight Bag Operational Authorization Process
    - AC 25-11A: Electronic Flight Deck Displays
    - AC 120-76: Guidelines for the Certification, Airworthiness, and Operational Approval of Electronic Flight Bag Computing Devices
    - AC 20-173: Installation of Electronic Flight Bag Components

    Note: The documents listed above may be revised occasionally. The reader should refer to the latest version.
2. To ensure ease of navigation through a document, the following guidelines should be considered when designing hypertext and providing links within the electronic document:
    - Minimize or eliminate the use of links if there is a linear course of action required (e.g. in checklists where a sequential list of steps needs to be taken)
    - Provide a history or overview of link selections so that the user has awareness of the sequence of actions taken to arrive at the current selection (see section 3.4.1 of Chandra, Yeh, Mangold and Riley, 2003)
    - Provide an easy method to return to the original or previous sections of text that were being read (FAA Order 8900.1; also see sections 2.4.18 and 3.4.1 of Chandra, Yeh, Mangold and Riley, 2003)
    - Provide an overview of spatial information if possible so that users who are zoomed in can also locate themselves within the larger context
    - Provide an easy method for users to switch between detailed and global views (see section 6.2.5 of Chandra, Yeh, Mangold and Riley, 2003)
3. To ensure crewmembers are able to interact with electronic documents in ways familiar to them when using paper, efforts should be made to allow crewmembers to customize the electronic documents they use. These capabilities might include:
    - Highlighting
    - Annotating
    - Underlining
    - Bookmarking

Retaining these edits and annotations in subsequent updates to electronic documents or manuals is recommended.

The review and recommendations provided in this document serve as a starting point upon which the usability of electronic documents may be assessed. The review highlights issues that should be considered and also presents various interface techniques that could augment the use of electronic media on the flight deck. However, it is critical to any development of EFB related products for pilots that proper usability studies be conducted. The product must be developed within a framework in which the pilot’s tasks are clearly understood. This will ensure that proper interaction techniques, functionality, and capabilities are developed.

5 List of References

Antin, J.F., Dingus, T.A., Hulse, M.C., and Wierwille, W.W. (1990). An evaluation of the effectiveness and efficiency of an automobile moving-map navigational display. International Journal of Man-Machine Studies, 33(5), 581-594.

Ballantyne, C. (2008, December 23). Online v. print reading: Which one makes us smarter? Scientific American, Retrieved from http://www.scientificamerican.com/blog/post.cfm?id=online-v-print-reading-which-one-ma-2008-12-23

Bartram, L., Ho., A., Dill, J., and Henigman, F. (1995). The continuous zoom: A constrained fisheye technique for viewing and navigating large information spaces. Proceedings of the 8th Annual ACM Symposium on User Interface and Software Technology, Pittsburgh, PA.

Batson, V.M., Harris, R.L., and Hunt, P.J. (1994). Navigating the airport surface: Electronic vs. paper maps. Proceedings of the 13th Digital Avionics Systems Conference. IEEE/AIAA Cambridge, MA.

Battiste, V., Downs, M., and McCann, R.S. (1996). Advanced Taxi Map Display Design for Low-Visibility Operations. In Proceedings of the Human Factors and Ergonomics Society 40th Annual Meeting, Philadelphia, PA.

Baudisch, P., Good, N., Bellotti, V., and Schraedley, P. (2007). Keeping things in context: A comparative evaluation of focus plus context screens, overviews, and zooming. Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. Minneapolis, MN.

Chandra, D.C., Yeh, M., Riley, V., and Mangold, S.J. (2003). Human Factors Considerations in the Design and Evaluation of Electronic Flight Bags (EFBs) Version 2. (Report No. DOT-VNTSC-FAA-03-07). Cambridge, MA: USDOT Volpe Center.

de Jong, T., and van der Hulst (2002). The effects of graphical overviews on knowledge acquisition in hypertext. Journal of Computer Assisted Learning, 18(2), 219-231.

Dillon, A. (1992). Reading from paper versus screens: a critical review of the empirical literature. Ergonomics, 35(10), 1297-1326.

Dingus, T.A., Antin, J.F., Hulse, M.C., and Wierwille, W.W. (1989). Attention demand requirements of an automobile moving-map navigation system. Transportation Research, 23, 301-315.

Dingus, T.A., Hulse, M.C., Mollenhauer, M.A., Fleischman, R.N., Mcgehee, D.V., and Manakkal, N. (1997). Effects of ages, system experience, and navigation technique on driving with an advanced traveler information system. Human Factors, 39(2), 177-199.

Federal Aviation Administration Technical Center (January 1996). Human Factors Design Guide for Acquisition of Commercial-Off-the-Shelf Subsystems, Non-Developmental Items, and Developmental Systems – Final Report and Guide.

Frenckner, K. (1993). The problem of getting a global perspective when reading continuous texts from a computer screen. Technical Report TRITA-NA-P9332, KTH Royal Institute of Technology.

Gould, J. D., and Grischkowsky, N. (1984). Doing the same work with hard copy and with cathode-ray tube (CRT) computer terminals. Human Factors, 26, 323-337.

Gould, J.D., Alfaro, L., Barnes, V., Finn, R., Grischkowsky, N., and Minuto, A. (1987a). Reading is slower from CRT displays than from paper: attempts to isolate a single-variable explanation. Human Factors, 29, 269-299.

Gould, J.D., Alfaro, L., Finn, R., Haupt, B., Minuto, A., and Salaun, J. (1987b). Why reading was slower from CRT displays than from paper. In Proceedings of the SIGCHI/GI Conference on Human Factors in Computing Systems and Graphics Interface, pp 7-11. ACM: New York, NY.

Hamblin, C. (2004). Usability of mobile devices in the cockpit. Usability News 6(1). Retrieved from http://www.surl.org/usabilitynews/61/efb.asp

Hansen, W.J, and Haas, C. (1988). Reading and writing with computers: A framework for explaining differences in performance. Communications of the ACM, 31(9), 1080-1089.

Hofman, R., and van Oostendorp, H. (1999). Cognitive effects of a structural overview in a hypertext. British Journal of Educational Technology, 30(2), 129-140.

Holzinger, A., Baernthaler, M., Pammer, W., Katz, H., Bjelic-Radisic, V., and Ziefle, M. (2011). Investigating paper vs. screen in real-life hospital workflows: Performance contradicts perceived superiority of paper in the user experience. International Journal of Human-Computer Studies, 69, 563-570.

Kim, H.J., and Kim, J. (2012). Reading from an LCD monitor versus paper: Teenager's reading performance. International Journal of Research Studies in Educational Technology, 1(1), 1-10.

Kroft, P., and Wickens, C.D. (2002). Displaying multi-domain graphical database information: A evaluation of scanning, clutter, display size and user activity. Information Design Journal, 11(1), 44-52.

Kruk, R.S., and Muter, P. (1984). Reading continuous text on video screens. Human Factors 26(3), 339-345.

Lee, W., and Cheng, B. (2008). Effects of using a portable navigation system and paper map in real driving. Accident Analysis and Prevention, 40, 303-308.

Lee, M.J., and Tedder, M.C. (2003). The effects of three different computer texts on readers' recall: based on working memory capacity. Computers in Human Behavior (19), 767-783.

Mangen, A. (2008). Hypertext fiction reading: haptics and immersion. Journal of Research in Reading, 31(4), pp404-419.

McCann, R.S., Foyle, D.C., Andre, A.D., and Battiste, V. (1996). Advanced navigation aids in the flight deck: Effects on ground taxi performance under low visibility conditions. Proceedings of the SAE/AIAA World Aviation Congress.

McDonald, S., and Stevenson, R.J. (1996). Disorientation in hypertext: the effects of three text structures on navigation performance. Applied Ergonomics, 27(1), 61-68.

Miall, D.S., and Dobson, T. (2001). Reading hypertext and the experience of literature. Journal of Digital Information, 2(1), 1-20.

Miratech. (n.d.). Readers are more likely to skim over articles on an iPad than in a newspaper. Retrieved from http://miratech.com/blog/eye-tracking-etude-iPad-vs-journal.html

Muter, P. (1996). Interface design and optimization of reading of continuous text. In van Oostendorp, H., and de Mul, S. (Eds.). Cognitive aspects of electronic text processing. Norwood, N.J.: Ablex.

Muter, P., Latremouille, S.A., Treurniet, W.C., and Beam, P. (1982). Extended reading of continuous text on television screens. Human Factors, 24(5), 501-508.

Muter, P., and Maurutto, P. (1991). Reading and skimming from computer screens and books: the paperless office revisited? Behavior and Information Technology, 10(4), 257-266.

Nielsen, J. (1990). The art of navigation through hypertext. Communications of the ACM, 33, 296-310.

Nomura, A., Hutchins, E., and Holder, B.E. (2006). The uses of paper in commercial flight operations. In Proceedings of the 20th Anniversary Conference on Computer Supported Cooperative Work, Banff, Alberta, pp. 249-258. ACM: New York, NY.

O'Hara, K., and Sellen, A. (1997). A comparison of reading paper and on-line documents. In Proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems, Atlanta, GA, pp. 335-342. ACM: New York, NY.

Pedersen, P., Farrell, P., and McPhee, E. (2007). Paper versus pixel: Effectiveness of paper versus electronic maps to teach map reading skills in an introductory physical geography course. Journal of Geography, 104(5), 195-202.

Potelle, H., and Rouet, J.F. (2003). Effects of content representation and readers' prior knowledge on the comprehension of hypertext. International Journal of Human-Computer Studies, 58(3), 327-345.

Schilit, B.N., Golvchinsky, G., and Price, M.N. (1998). Beyond paper: Supporting active reading with free form digital ink annotations. In Proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems, Los Angeles, CA, pp. 249-256. ACM: New York, NY.

Sellen, A., and Harper, R. (1997). Paper as an analytic resource for the design of new technologies. In Proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems, Atlanta, GA, pp. 319-326. ACM: New York, NY.

Shin, E.C., Schallert, D.L., and Savenye, W.C. (1994). Effects of learner control, advisement, and prior knowledge on young students' learning in a hypertext environment. Journal of Educational Computing Research, 20(2), 143-167.

Shamo, M.K., Dror, R., and Degani, A. (1998). Evaluation of a new cockpit device: The integrated electronic information system. In Proceedings of the Human Factors and Ergonomics Society 42nd Annual Meeting, Chicago, IL.

Spiro, R.J., and Jehng, J. (1990). Cognitive flexibility and hypertext: theory and technology for the nonlinear and multidimensional traversal of complex subject matter. In D. Nix and R. Spiro (Eds.), Cognition, Education and Multimedia: Exploring ideas in High Technology (pp. 163-205). Hillsdale, N.J.: Lawrence Erlbaum Associates.

Appendix A Acronyms

APU	Auxiliary Power Unit
CRT	Cathode Ray Tube
EFB	Electronic Flight Bag
FAA	Federal Aviation Administration
ICIS	Integrated Crew Information System
JPFD	JeppView Flight Deck
LCD	Liquid Crystal Display
LED	Light Emitting Diode
PCATD	Personal Computer based Aviation Training Device
PFD	Primary Flight Display